DARK INCLUSIONS IN THE CV3 CARBONACEOUS CHONDRITE EFREMOVKA: TEXTURAL AND MINERALOGICAL OBSERVATIONS. V. V. Biryukov[1], N. N. Korotaeva[1], E. V. Gouseva[1], A. N. Krot[2], and A. A. Ulyanov[1]; [1]Geological Faculty, Moscow State University, Moscow 119899, Russia, e-mail address: vvbir@geol.msu.ru; [2]Hawai'i Institute of Geophysics and Planetology, SOEST, University of Hawaii, Honolulu, HI 96822, USA.

Abstract. We studied three dark inclusions (DIs) in the reduced CV3 chondrite Efremovka (E81, E82, E90) using optical and scanning electron microscopy and electron probe microanalysis, in addition to E39, E53, and E80 characterized in detail by Krot et al. [1]. These DIs show moderate degree of alteration similar to those experienced by the Efremovka DI E39. They consist of chondrules and CAIs embedded in fine-grained, opaque matrices, rich in metal. In contrast to E39, sulfides are absent and Ca-rich rims around DIs are not observed. Low-Ca pyroxene, olivine and mesostasis in chondrules are completely replaced by an Fe-rich phase consisting mainly of fine-grained fayalitic olivine with minor interstitial, poorly-crystalline Si-Al-rich material and chlorite [1]. High-Ca pyroxene grains are stable to alteration. Chondrule pseudomorphs contain small grains of Ca-Ti-Fe-rich phase (possibly Ti-andradite), salite-ferrosalite pyroxene, and Fe-rich Cr-spinel. Small CAIs are abundant throughout the DIs; they consist of Al-diopside and fassaitic pyroxene rims surrounding cores composed of the Fe-rich phase. Based on mineralogical similarities between the DIs studied and those characterized by Krot et al. [1], we conclude that E81, E82, and E90 also experienced aqueous alteration and subsequent thermal metamorphism in asteroidal environment. Textural observations indicate that E81 and E82 are breccias containing clasts of various degrees of alteration. We infer that brecciation and aggregation of these DIs occurred after aqueous alteration and possibly postdated thermal metamorphism.

Introduction. Dark inclusions provide important information about nebular and/or asteroidal alteration processes affecting their components [2-14] as well as CAIs, chondrules and matrices of the oxidized CV3 chondrites [10, 12, 14]. It was suggested that DIs in Allende, Vigarano and Leoville experienced various degrees of aqueous alteration and were subsequently metamorphosed in asteroidal environment and that these processes resulted in formation of fayalitic olivine and secondary Ca-rich phases [4, 8-12 , 14]. The discovery of relict chlorite coexisting with secondary, fine-grained fayalitic olivine in Efremovka DIs [1] strongly support this model. However, many questions about formation history of CV3 DIs remain to be answered; e.g., precursor materials of the DIs in CV3s and their geological position within CV3 or other parent asteroid(s), temperature and duration of aqueous alteration and thermal metamorphism, changes in bulk chemical compositions and oxygen isotopic compositions during these processes. In this paper, we describe mineralogical and textural observations on three DIs (E81, E82, E90) in the reduced CV3 chondrite Efremovka.

Mineralogy and petrography. The Efremovka DIs studied consist of chondrules, CAIs and mineral grains embedded in fine-grained, opaque matrix, rich in metal; magnetite and sulfide grains are not observed. All coarse-grained components are replaced to various degrees by an Fe-rich phase with an olivine composition (Fa36-43, in wt.%, Al_2O_3, 1.3±0.6; Cr_2O_3, 0.4±0.4; CaO, 0.4±0.1; Na_2O, up to 1.1; SO_2, up to 1.0). The Fe-rich phase probably consists of abundant, fine-grained fayalitic olivine with small amounts of interstitial, poorly-crystallized Si-Al-rich material, and chlorite, as was shown for several other DIs in Efremovka [1]. The degree of alteration increases in the order low-Ca pyroxene, plagioclase mesostasis, opaque nodules, olivine, and high-Ca pyroxene. Relict grains of olivine and high-Ca pyroxene are common in many chondrule pseudomorphs. Pseudomorphs after chondrule phenocrysts commonly show layered textures and contain small grains of a Ca-Ti-Fe-rich phase, possibly Ti-andradite. Small (<150 µm) CAIs are abundant throughout the DIs; they consist of Al-diopside and fassaitic pyroxene rims surrounding cores completely replaced by an Fe-rich phase which is compositionally similar to those in chondrules. Metal nodules consist of kamacite (3.6-6.0 wt.% Ni, 1.2-4.0 wt.% Co) and taenite (33.4-47.0 wt.% Ni, up to 2.4 wt.% Co).

E81 and E82 show brecciated textures. E81 contains chondrules with unaltered phenocrysts of forsteritic olivine, glassy mesostasis, troilite, metal nodules and unaltered, fine-grained CAIs. The unaltered chondrules and CAIs are observed in the center of the DI and do not show any evidence of interaction with the host DI. E82 contain chondritic clast which is more heavily altered than the host DI; it contains a large (1200x600µm) altered porphyritic chondrule. The chondrule phenocrysts are replaced by the Fe-rich phase and surrounded by euhedral grains of chromite [Cr/(Cr+Al) = 0.4-0.8, $Fe_{tot}/(Fe_{tot}+Mg)$ = 0.5-0.7]; mesostasis is replaced by Fe-rich phase and contains skeletal aggregates of euhedral pyroxene crystals (Fig. A) which vary in composition from Fs40Wo9 (core) to Fs32Wo31 (rim). The chondrule is surrounded by a very fine-grained mixture of fayalitic olivine, Fe-Ni metal, and Ca-rich phase, possibly diopsidic pyroxene. The boundary between E82 and host Efremovka is marked by tiny metal nodules and veins, possibly indicating melting during shock metamorphism.

Discussion. The DIs studied are moderately altered and texturally and mineralogically similar to the Efremovka DI E39 described in detail by Krot et al. [1]. Based on these similarities, it seems likely that the Fe-rich phase replacing coarse-grained components in E81, E82, and E90 consists of fine-grained fayalitic olivine with small amounts of interstitial, poorly-crystallized Si-Al-rich material, and chlorite, like in other Efremovka DIs [1]. We infer that all Efremovka DIs studied so far experienced similar alteration processes: aqueous alteration and subsequent thermal metamorphism resulting in incomplete dehydration of phyllosilicates, growth of fayalitic olivine and Ti-andradite (?). Small crystals of Fe-rich Cr-spinel are either primary crystals enriched in Fe and Cr during thermal metamorphism or were formed during this process. Euhedral pyroxene grains (Fig. A) can formed during primary chondrule glass decay or subsequent alteration. Increasing of Wo contents from core to rim of pyroxene grains is disagree with first suggestion. Moreover discordant location of pyroxene grains to mesostasis and former olivine phenocryst (Fig. B) indicates that pyroxene was formed after main alteration and replacement event. Probably pyroxene formation occured on the stage of dehydration and linked with decay of phyllosilicate and releasing of excess Ca and Al.

The presence of unaltered chondrules and CAIs in E81 and clasts with various degrees of alteration in E82 indicate that these DIs were brecciated and aggregated after aqueous alteration. The presence of unaltered glasses in these chondrules may suggest that dehydration either predated brecciation and agglomeration or it occurred at temperatures low enough to preserve glass in their mesostases. After brecciation, the DIs were excavated from their original location and incorporated into the host Efremovka. The coarse-grained components of the most of the Efremovka DIs are flattened (~1:2) and elongated in the same orientation as chondrules and CAIs in the host Efremovka, probably due to late-stage shock event. The occurrence of tiny metal droplets and veins around E82 probably supports this suggestion.

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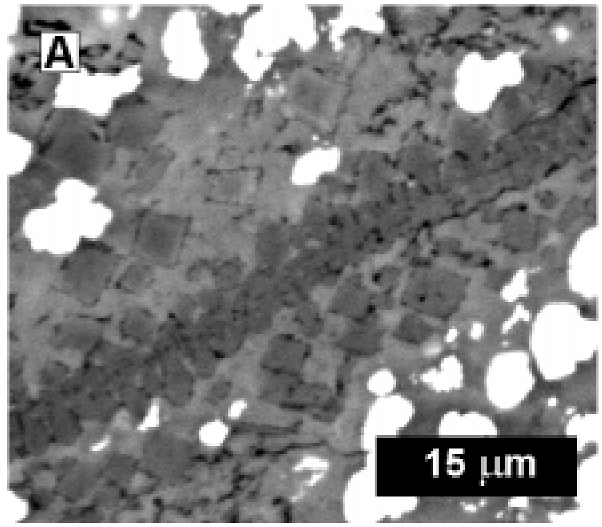

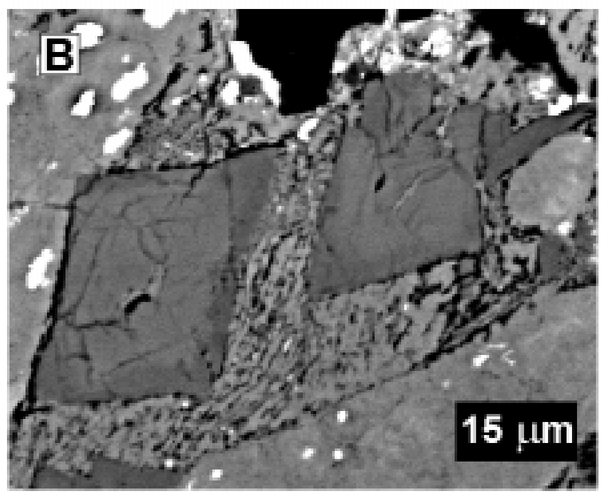

Fig. Backscattered images of DI E82.
A. Euhedral grains of pyroxene (dark) form skeletal aggregates in fayalitic olivine (gray). White grains are chromite.
B. Large zonal crystals of pyroxene (dark) in chondrule mesostasis between olivine phenocrysts. White grains are chromite.